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PACIFIC SOUTHWEST
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UNDERPLANTING TRIALS IN OHIA RAIN FORESTS

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In three 5- to 9-year-old trials on the island of Hawaii, eleven species were tested to determine their value for underplanting in ohia-treefern rain forests. These planting trials were established on organic muck soils overlying aa lava rock. Three species are recommended for future plantings. Annual height and diameter (b.h.) growth of *Eucalyptus saligna* averaged 5.9 feet (1.8 m) and 0.6 inch (1.4 cm); *Flindersia brayleyana* 4.8 feet (1.4 m) and 0.4 inch (1.1 cm); and *Toona ciliata* var. *australis* 4.0 feet (1.2 m) and 0.5 inch (1.2 cm). Survival of these three Australian species was 71 percent or greater. The valuable native *Acacia koa* proved unsatisfactory. The five African species tested failed. Despite high survival and rapid growth, *Fraxinus uhdei* was judged of little value because of extremely poor form. In the two adjacent trials at 2850 feet (869 m) elevation, most species performed better in bulldozed lanes than in lines where the vegetation was only lightly cut back, with machetes. The species planted at 820 feet (250 m) elevation grew faster there than at 2850 feet.

Oxford: 235.1(969):232.11[+176.1 *Eucalyptus saligna* + 176.1 *Flindersia brayleyana* + 176.1 *Toona ciliata*].
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Hawaii's rain forests yield little merchantable timber. The predominant species are koa (*Acacia koa* Gray) and ohia (*Metrosideros collina* [Forst.] Gray). Koa timber is valuable, but the total supply is less than 200 million board feet. Ohia has low commercial value because of its poor form and quality, and is seldom manufactured into lumber.

Underplanting native forests is a silvicultural practice that foresters have tried in many tropical and subtropical regions.[1] Underplanting involves the introduction of valuable timber species into understocked or low-value forest stands. Both introduced and native timber species are used. Various techniques are employed to plant seedlings in cleared patches or lines beneath the existing forest canopy. Benefits of underplanting include reduced costs for site preparation, greater protection of the soil from erosion, and less disturbance to the plant and animal community. Difficulties inherent in underplanting operations usually include increased costs for weed control, inadequate openings in the canopy for light to penetrate, and minimal stocking with preferred species at time of harvest.

This study, started in 1966 by the U.S. Forest Service in cooperation with the Hawaii Division of Forestry, was designed to answer this question: How do selected native and introduced timber species perform, in terms of survival, growth, and form, when underplanted in ohia-treefern rain forests?

This note reports 9-year results from two underplantings and 5-year results from a third trial.

STUDY SITES

The three planting trials are in the Waiakea Forest Reserve, from 7 to 10 miles (11 to 16 km) southwest of the coastal town of Hilo, on the island of Hawaii. Two of the trials are at elevations of about 2850 feet (869 m), latitude 19° 34′ 38″ N and longitude 155° 13′ 04″ W. Mean annual rainfall at 2800 feet (853 m) elevation was 206 inches (5227 mm), with extremes

ranging from 167 to 270 inches (4242 to 6858 mm) annually during the period 1965-1974. The mean annual temperature was 64° F (18° C). The lowest temperature recorded was 41° F (5° C); the highest was 87° F (31° C). Aspect is northeast to east, with slopes of 1 to 20 percent. The third trial is at an elevation of 820 feet (250 m); latitude 19° 37′ 23″ N and longitude 150° 05′ 23″ W. Aspect is generally east to northeast, with slopes of from 1 to 15 percent. Annual rainfall averages about 200 inches (5000 mm), and is distributed rather uniformly throughout the year. Rainfall for any given month varies greatly from year to year, however.

The native rain forest vegetation consists of an overstory of ohia, with treefern (*Cibotium* spp.) dominating the understory. Many other plant species occur, the more abundant being mamaki (*Pipturus albidus* H. and A. Gray), oi (*Verbene litoralis* HBK.), Indian pluchea (*Pluchea indica* L.), and 'ie'ie (*Freycinetia arborea* Gaud.).

The ground is very rough and was little modified by the bulldozers which cleared the lanes. The soils consist of a surface layer of very dark brown organic material from 3 to 10 inches (7 to 25 cm) thick, overlying aa lava rock. Slightly weathered ash and cinders fill the voids between the pieces of lava. These tropical soils shrink greatly when dried, have low inherent fertility, and are acidic (pH 5.0 to 6.0). Soil depth and soil drainage vary greatly within short distances. Under such edaphic conditions, high initial survival of planted stock and uniform stocking are difficult to obtain.

GENERAL METHODS

Heights to the nearest foot were measured at the end of the first, second, and fifth years. After the fifth year, total height, height to live crown, diameter (d.b.h.) in tenths of an inch, vigor (rated either good or poor), and stem quality class were recorded. The stem quality of each tree was graded as "desirable," "acceptable," or "cull." A desirable tree was one having good vigor, no serious defects, and no evidence of disease. Specifically, the tree must have had, or could potentially have, a sawlog length of more than 32 feet (10 m) and no defect, as judged from a list of common defects. An acceptable tree had, or had the potential for, a butt sawlog length of at least 12 feet (3.7 m) without serious defect. The list included forking, excessive sweep or crook, lodging, lean exceeding 8 degrees, heavy branching below 12 feet, and being overtopped and low in vigor.

Plot means for survival, height, and diameter were subjected to analysis of variance and to Duncan's multiple range test. Differences at the 0.05 level were considered significant. Arc-sin transformations were applied to survival percentages before the statistical analysis was performed.

TRIAL PROCEDURES AND RESULTS

Trial 1
Elevation 2860 (872 m)

Establishment

In 1966 nine non-native species were planted along bulldozed lanes 12 feet (3.7 m) wide:

Chlorophora excelsa Benth. & Hook. (Iroko), from Nigeria

Entandrophragma utile Sprague (Utile), from Ghana

Eucalyptus robusta Sm. (Robusta eucalyptus), from Australia

Eucalyptus saligna Sm. (Saligna eucalyptus), from Australia

Flindersia brayleyana (F.v.M.) (Queensland-maple), from Australia

Fraxinus uhdei (Wenzig) Lingelsh. (Tropical ash), from Mexico

Mimusops heckelii Hutch. & Dalz. (Makore), from Ghana

Pericopsis elata (Harms) van Meeuwen (Afrormosia), from Ghana

Toona ciliata var. *australis* (F.v.M.) C. Dc. (Toona), from Australia

Seedlings of the native *Acacia koa* were not available, so seeds were sown in prepared spots, 3 months later. Six seeds were sown at each spot.

Species were planted in a complete randomized block design, and each species was replicated twice in 10-tree row plots. Seedlings were spaced from 6 to 34 feet (2 to 10 m) apart within rows, with the average distance about 9 feet (2.7 m). The distance between the bulldozed lanes averaged about 33 feet (10 m). Seedlings that died during the first 6 months were replaced. Treefern fronds overhanging the lanes and within reach, and aggressive weeds, were cut back periodically.

Performance at age 8.7 years

See *table 1.* *Survival* for six species ranged from a high of 100 percent for *Fraxinus uhdei* to a low of 40 percent for *Acacia koa.* The four African species—*Chlorophora excelsa, Pericopsis elata, Mimusops heckelii,* and *Entandrophragma utile*—failed during the first 5 years.

Table 1—*Survival, height, mean annual height increment, diameter, and condition at age 8.7 years of six tree species in Underplanting Trial 1, Waiakea Forest Reserve, island of Hawaii*

Species	Number planted	Survival[1]	Height			Percent stem in live crown	Average diameter[1]	Good vigor	Stem quality class		
			Average[1]	Extremes	Mean annual increment				Desirable	Acceptable	Cull
		Percent	*Feet*				*Inches*	*Percent*			
Acacia koa[2]	20	40	32	21-42	3.7	59	3.4	25	14	14	72
Eucalyptus robusta	20	70b	39a	15-55	4.6	53	4.3a	86	43	43	14
Eucalyptus saligna	20	75b	42a	15-65	4.8	44	4.1a	73	40	33	27
Flindersia brayleyana	20	85ab	31a	9-40	3.6	58	4.6a	94	41	47	12
Fraxinus uhdei	20	100a	44a	34-50	5.2	71	4.6a	95	5	25	70
Toona ciliata var. *australis*	20	90ab	32a	17-52	3.7	53	3.8a	56	53	35	12

[1] Values followed by the same letter do not differ significantly (5 percent level) by Duncan's test.

[2] Age 8.3 years, calculated from time of sowing. This species was excluded from statistical analysis.

Growth: Average total heights ranged from 31 feet (9.4 m) for *Flindersia brayleyana* to 44 feet (13.4 m) for *Fraxinus uhdei.* The tallest individual was a 65-foot (19.8 m) *Eucalyptus saligna.* The only species with less than half of its total height in live crown was *Eucalyptus saligna.* Average stem diameters ranged from 3.4 to 4.6 inches (8.6 to 11.7 cm) for the six species.

Vigor: Over 90 percent of the *Flindersia brayleyana* and *Fraxinus uhdei* saplings were judged vigorous, whereas only 25 percent of the *Acacia koa* saplings appeared thrifty.

Tree quality: All four species from Australia exhibited acceptable or desirable tree quality. Nearly three-fourths of the native *Acacia koa* and the non-native *Fraxinus uhdei* were rated as cull trees.

Trial 2
Elevation 2840 feet (866 m)

Establishment

In 1966 nine non-native species were planted along hand-cleared lines about 6 feet (1.8 m) wide, near Trial 1:

Chlorophora excelsa (Iroko), from Nigeria

Entandrophragma utile (Utile), from Ghana

Eucalyptus robusta (Robusta eucalyptus), from Australia

Eucalyptus saligna (Saligna eucalyptus), from Australia

Flindersia brayleyana (Queensland-maple), from Australia

Fraxinus uhdei (Tropical ash), from Mexico

Pericopsis elata (Afrormosia), from Ghana

Terminalia superba Engl. & Diels (White afara), from Ghana

Toona ciliata var. *australis* (Toona), from Australia

Koa seeds were sown in prepared seed spots (6 seeds per spot) 3 months later.

Thirty seedlings of each species were planted in a complete randomized block design replicated three times. Each plot contained 10 seedlings of a single species, planted in a row. Seedlings and seed spots were spaced from 6 to 40 feet (2 to 12 m) apart, averaging 11 feet (3.4 m) depending upon site conditions. Seedlings that died during the first 6 months were replaced. The hand-cleared lines ran more or less straight, occasionally veering away from the trunks of large ohia trees. The rows were spaced about 33 feet (10 m) apart. No ohia trees were killed. Treefern fronds within reach and those overhanging the lines were cut. Weedings during the 2d, 3d, and 5th year released suppressed seedlings.

Performance at age 8.7 years

See *table 2.*

Survival for six species ranged from a high of 87 percent for *Fraxinus uhdei* to a low of 20 percent for *Eucalyptus robusta.* The four African species—*Chlorophora excelsa, Entandrophragma utile, Pericopsis elata,* and *Terminalia superba*—failed within 5 years.

Growth: Average total heights ranged from 25 feet (7.6 m) for *Toona ciliata* v. *australis* to 44 feet (13.5 m) for *Fraxinus uhdei.* The tallest individual

Table 2–*Survival, height, mean annual height increment, diameter, and condition at 8.7 years of six tree species in Underplanting Trial 2, Waiakea Forest Reserve, island of Hawaii*

Species	Number planted	Survival[1]	Height			Percent stem in live crown	Average diameter[1]	Good vigor	Stem quality class		
			Average[1]	Extremes	Mean annual increment				Desirable	Acceptable	Cull
		Percent	*Feet*				*Inches*	*Percent*			
Acacia koa[2]	30	47	29	5-36	3.3	28	2.1	36	0	31	69
Eucalyptus robusta	30	20b	28b	20-33	3.2	39	1.9c	50	67	33	0
Eucalyptus saligna	30	30b	33ab	14-42	3.8	53	2.8bc	67	43	0	57
Flindersia brayleyana	30	77a	28b	14-39	3.2	77	3.1ab	91	28	36	36
Fraxinus uhdei	30	87a	44a	27-57	5.1	76	4.3a	88	4	15	81
Toona ciliata var. *australis*	30	77a	25b	12-40	2.9	46	2.6bc	52	22	39	39

[1] Values followed by the same letter do not differ significantly (5 percent level) by Duncan's test.

[2] Age 8.3 years, calculated from time of sowing. This species excluded from statistical analysis.

was a 57-foot (17.4 m) *F. uhdei.*

The average proportion of stem in live crown ranged from over 75 percent for *Flindersia brayleyana* and *Fraxinus uhdei* down to only 28 percent for *Acacia koa.* Average stem diameters ranged from 1.9 inches (4.8 cm) for *Eucalyptus robusta* to 4.3 inches (10.9 cm) for *Fraxinus uhdei.*

Vigor: Two-thirds or more of the *Eucalyptus saligna, Flindersia brayleyana,* and *Fraxinus uhdei* saplings were rated as vigorous. One-half of the *E. robusta* and *Toona ciliata* var. *australis,* and only one-third of the *Acacia koa* were healthy, vigorous trees.

Tree quality: Three species–*Eucalyptus robusta, Flindersia brayleyana,* and *Toona ciliata* var. *australis* were of somewhat better quality than the other species, with 61 percent or more trees classified as either desirable or acceptable. Fifty-seven percent of the *Eucalyptus saligna* were classed as culls, as were 69 percent of the *Acacia koa* and 81 percent of the *Fraxinus uhdei.*

Trial 3
Elevation 820 feet (250 m)

Establishment

In 1969 three non-native hardwood species were planted in 16-foot wide (5 m) bulldozed lanes:

Eucalyptus saligna (Saligna eucalyptus)
Flindersia brayleyana (Queensland-maple)
Toona ciliata var. *australis* (Toona)

Table 3–*Survival, height, mean annual height increment, diameter, and condition at age 5.4 years of three introduced tree species in Underplanting Trial 2, Waiakea Forest Reserve, island of Hawaii*

Species	Number planted	Survival[1]	Height			Stem in live	Average diameter[1]	Good vigor	Stem quality class		
			Average[1]	Extremes	Mean annual increment				Desirable	Acceptable	Cull
		Percent	*Feet*				*Inches*	*Percent*			
Eucalyptus saligna	152	78a	34a	12-64	6.2	52	3.2a	71	58	10	32
Flindersia brayleyana	152	86a	23b	9-39	4.2	74	2.2c	94	33	17	50
Toona ciliata var. *australis*	152	88a	28b	12-52	5.2	31	2.7b	77	63	28	9

[1] Values followed by the same letter do not differ significantly (5 percent level) by Duncan's test.

The bulldozed lanes were spaced about 50 feet (15 m) apart, and 152 seedlings of each species were planted in a complete randomized block design replicated four times. Each plot contained 38 seedlings of a single species. The seedlings were planted at least 6 feet (1.8 m) apart along both edges of the bulldozed lanes. Seedlings that died during the first 2 months were replaced.

Performance at age 5.4 years

See *table 3.*

Survival exceeded 77 percent, and there were no statistically significant survival differences among the three species.

Growth: Eucalyptus saligna was the fastest growing species, averaging 34 feet (10.4 m) in height for the 5.4-year trial period. The tallest individual was a 64-foot (19.5 m) *E. saligna.* Height of *Toona ciliata* var. *australis* averaged 28 feet (8.6 m), compared to 23 feet (6.9 m) for *Flindersia brayleyana.* The average proportion of stem in live crown ranged from 74 percent for *F. brayleyana* to 31 percent for *Toona ciliata* var. *australis.* Average d.b.h. ranged from 2.2 inches (6 cm) for *Flindersia brayleyana* to 3.2 inches (8 cm) for *Eucalyptus saligna.*

Vigor: Ninety-four percent of the *Flindersia brayleyana* showed good vigor, while only 77 percent of the *Toona ciliata* var. *australis* and 71 percent of the *Eucalyptus saligna* were rated as vigorous.

Tree quality: Toona ciliata var. *australis* were generally of better quality than the *Eucalyptus saligna* and *Flindersia brayleyana*–with 91 percent classified as desirable or acceptable. Only 68 percent of the *E. saligna* and 50 percent of the *F. brayleyana* were rated either desirable or acceptable.

DISCUSSION AND RECOMMENDATIONS

On the basis of survival, growth, and stem form *Flindersia brayleyana, Eucalyptus saligna,* and *Toona ciliata* var. *australis* are recommended for underplantings on stony muck soils on the island of Hawaii. These three Australian species grew best at the lower elevation test site, where the bulldozed lanes were wider. Trees planted at this elevation benefit from increased light intensity and temperature. At the higher elevation sites, the almost continuous cloud cover limits insolation, causing lower air and soil temperatures. There, the plantings in the narrow hand-cleared lines were generally poorer than those in bulldozed lanes.

Over the years, few introduced species have proved useful for timber production on these sites.[2] The African species, tested at the higher elevation sites, were no exception–all five failed. *Fraxinus uhdei,* from Mexico, grew faster when underplanted than when outplanted in open areas.[3] Despite high survival and rapid growth, this species proved unsuitable for underplantings because of its extremely poor form and its tendency to lodge. The native *Acacia koa,* a light demanding species, also proved unsatisfactory, exhibiting low vigor and form, and poor survival. During the first year koa seedlings were damaged or destroyed by wild pigs. *Eucalyptus robusta* demonstrated acceptable growth, but given a choice, foresters in Hawaii prefer *E. saligna* for reforestation on most sites because of its superior form and faster growth.

When this study was started, underplantings in the ohia rain forests seemed an economically feasible method of reforestation on the windward slopes of the island of Hawaii. Since then many of the ohia trees have died on thousands of acres in this area, and the forest decline continues.[4] When and if the rehabilitation of these forest lands is undertaken, the three promising species identified in these trials should be considered in the planting program.

NOTES

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[2] Burgan, Robert E., and Wesley H. C. Wong, Jr. 1971. *Species trials at the Waiakea Arboretum-tree measurements in 1970.* USDA Forest Serv. Res. Note PSW-240, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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